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(54) **SERVO CONTROL DEVICE FOR PERFORMING CORRECTION BASED ON AMOUNT OF STRETCH OR CONTRACTION OF BALL SCREW**

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G05B 19/404 (2006.01)

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CPC ***G05B 13/024*** (2013.01); ***G05B 19/404*** (2013.01)

(58) **Field of Classification Search**
CPC G05B 13/024
USPC 318/685, 671, 560
See application file for complete search history.

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(57) **ABSTRACT**

A servo control device in the present invention corrects a position command to a feed axis, so as to compensate for an amount of stretch or contraction of a ball screw during operation, by taking into account an influence of tension applied to the ball screw. The amount of stretch or contraction of the ball screw is calculated, based on the tension acting on the ball screw on the side farther from the servo motor, a distance between two fixed units supporting the ball screw at its opposite ends, a distance from the fixed unit situated closer to the servo motor to a moving body, and a torque command to the servo motor. An amount of position correction of the feed axis is calculated, based on the calculated amount of stretch or contraction of the ball screw.

6 Claims, 5 Drawing Sheets

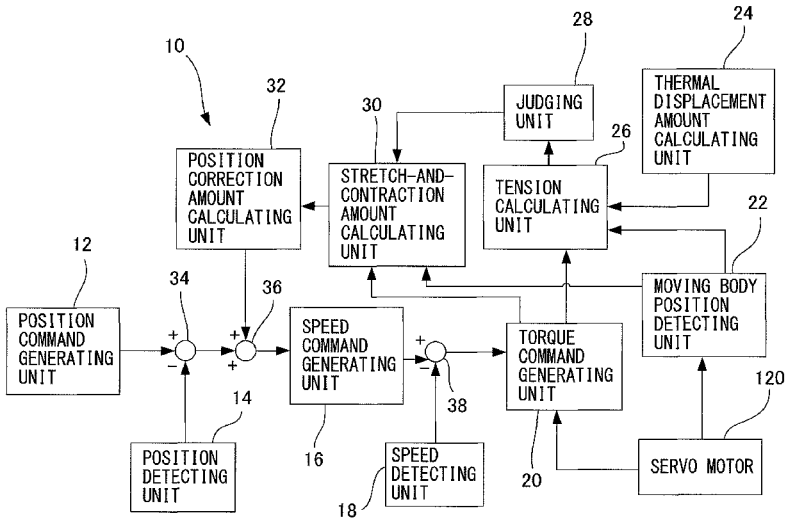


FIG. 1

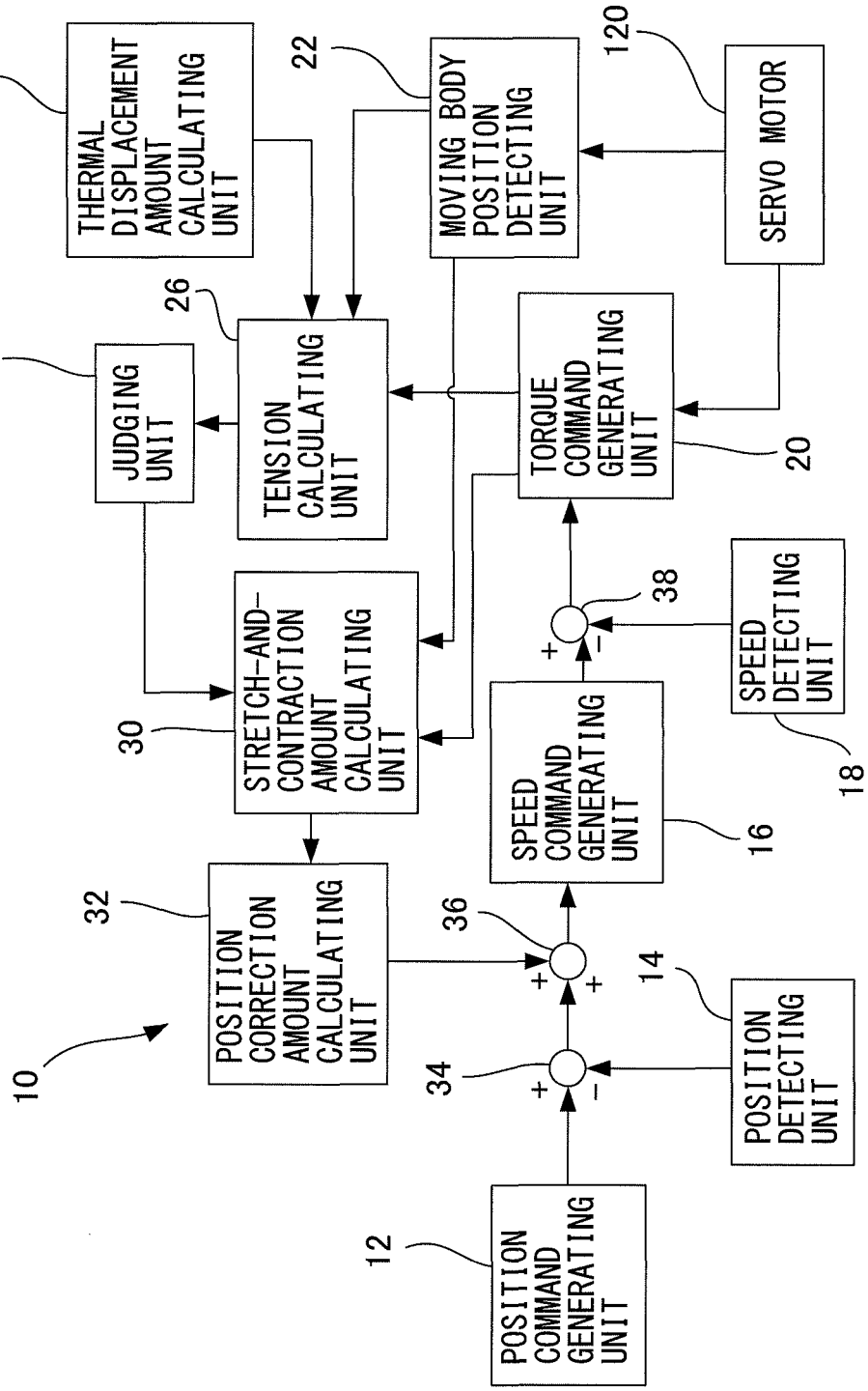

THERMAL DISPLACEMENT AMOUNT CALCULATING UNIT
24
MOVING BODY POSITION DETECTING UNIT
22
SERVO MOTOR
120
JUDGING UNIT
28
TENSION CALCULATING UNIT
26
TORQUE COMMAND GENERATING UNIT
20
STRETCH-AND-CONTRACTION AMOUNT CALCULATING UNIT
30
SPEED DETECTING UNIT
18
38
SPEED COMMAND GENERATING UNIT
16
POSITION CORRECTION AMOUNT CALCULATING UNIT
32
36
14
34
POSITION DETECTING UNIT
10
POSITION COMMAND GENERATING UNIT
12

FIG. 2

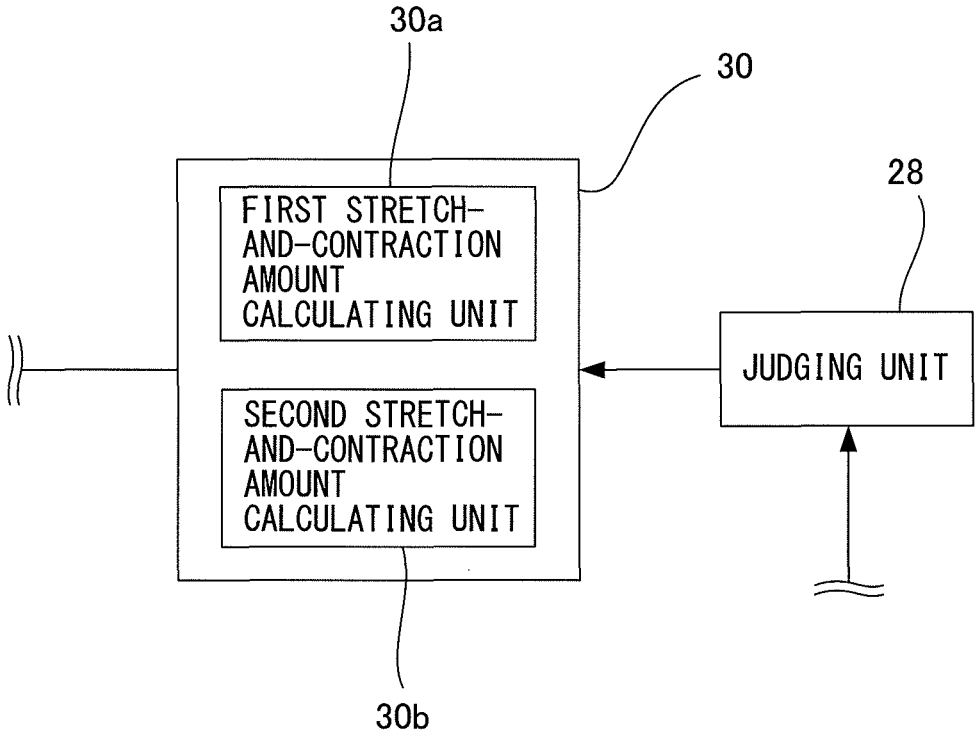

30a
30
28
FIRST STRETCH-AND-CONTRACTION AMOUNT CALCULATING UNIT
SECOND STRETCH-AND-CONTRACTION AMOUNT CALCULATING UNIT
JUDGING UNIT
30b

FIG. 3

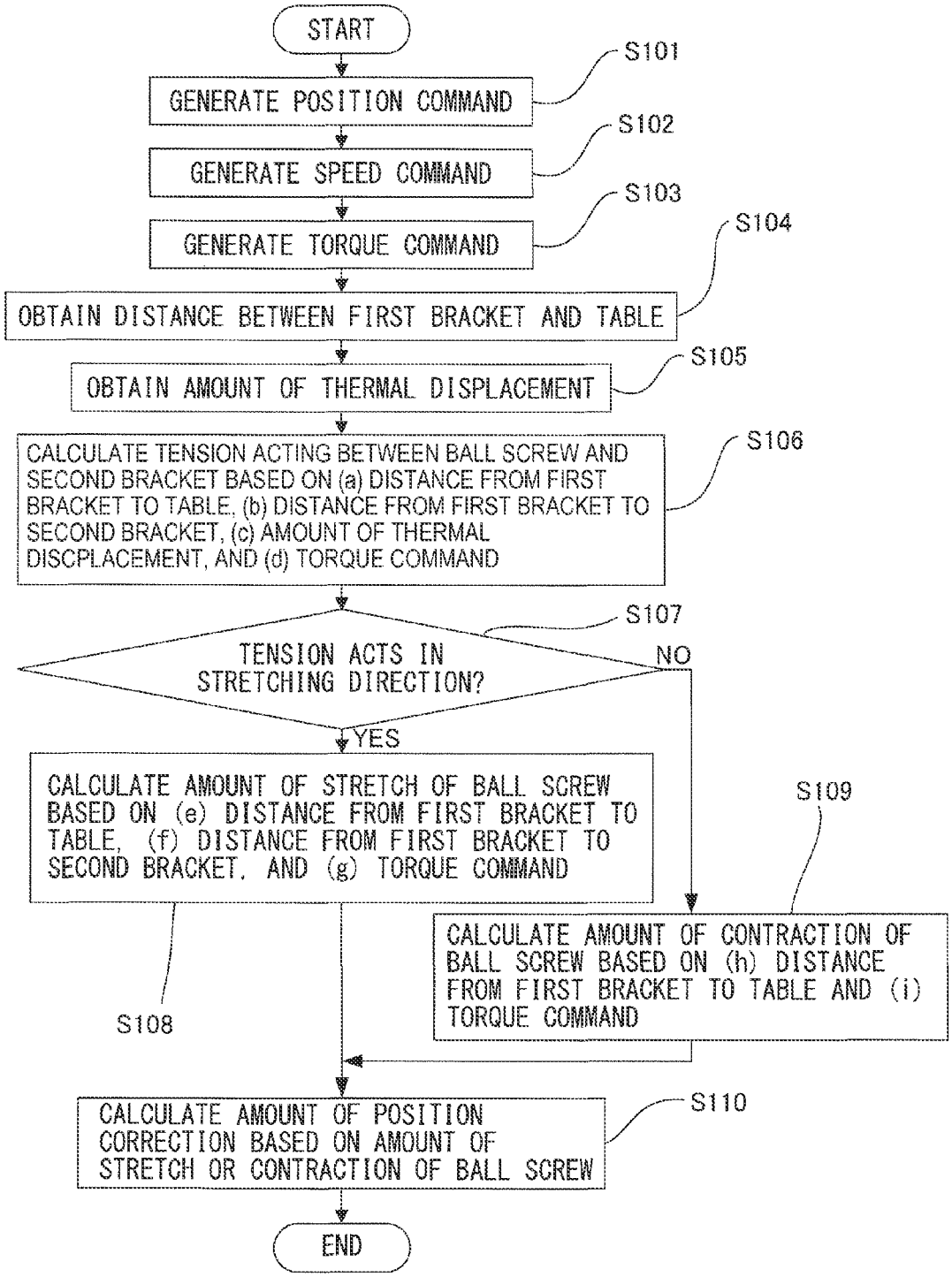
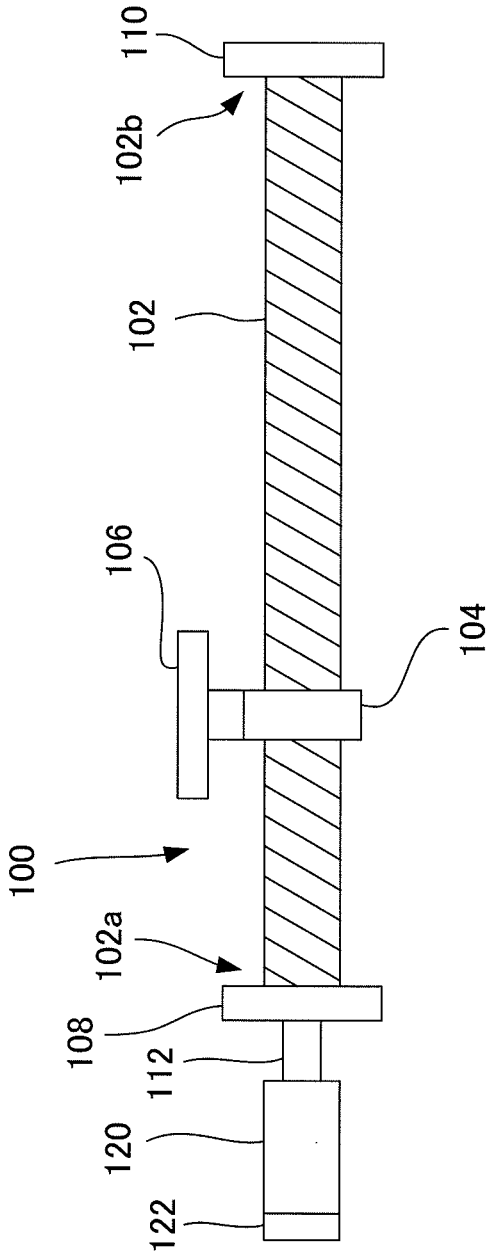

START
S101
GENERATE POSITION COMMAND
S102
GENERATE SPEED COMMAND
S103
GENERATE TORQUE COMMAND
S104
OBTAIN DISTANCE BETWEEN FIRST BRACKET AND TABLE
S105
OBTAIN AMOUNT OF THERMAL DISPLACEMENT
S106
CALCULATE TENSION ACTING BETWEEN BALL SCREW AND SECOND BRACKET BASED ON (a) DISTANCE FROM FIRST BRACKET TO TABLE, (b) DISTANCE FROM FIRST BRACKET TO SECOND BRACKET, (c) AMOUNT OF THERMAL DISCPLACEMENT, AND (d) TORQUE COMMAND
S107
TENSION ACTS IN STRETCHING DIRECTION?
NO
YES
CALCULATE AMOUNT OF STRETCH OF BALL SCREW BASED ON (e) DISTANCE FROM FIRST BRACKET TO TABLE, (f) DISTANCE FROM FIRST BRACKET TO SECOND BRACKET, AND (g) TORQUE COMMAND
S108
S109
CALCULATE AMOUNT OF CONTRACTION OF BALL SCREW BASED ON (h) DISTANCE FROM FIRST BRACKET TO TABLE AND (i) TORQUE COMMAND
S110
CALCULATE AMOUNT OF POSITION CORRECTION BASED ON AMOUNT OF STRETCH OR CONTRACTION OF BALL SCREW
END

FIG. 4



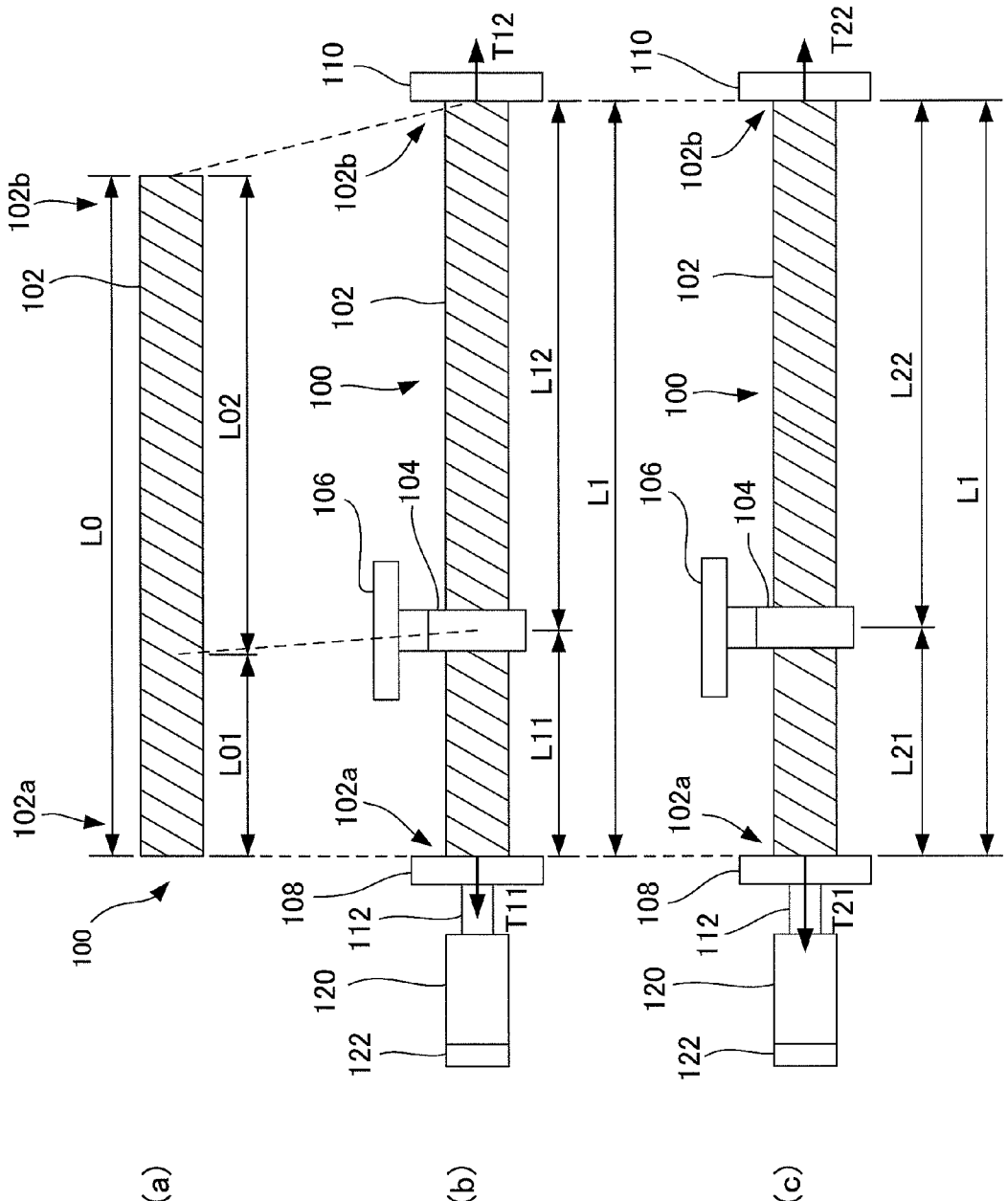

(a)
(b)
(c)
100
102
102a
102b
108
110
112
120
122
104
106
L0
L01
L02
L1
L11
L12
L21
L22
T11
T12
T21
T22

FIG. 5

SERVO CONTROL DEVICE FOR PERFORMING CORRECTION BASED ON AMOUNT OF STRETCH OR CONTRACTION OF BALL SCREW

RELATED APPLICATIONS

The present application is based on and claims priority to Japanese Application Number 2012-239048, filed Oct. 30, 2012, the disclosure of which is hereby incorporated by reference herein in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a servo control device for controlling a feed axis which converts rotational motion of a servo motor to linear motion of a moving body by way of a ball screw.

2. Description of the Related Art

A control device which can correct an error in positioning of a feed axis in the form of a ball screw has been known (see JP-B-4867105, JP-B-4503148, and JP-B-3292958). Such an error can be attributed to various factors. For example, JP-B-4867105 discloses a control device that corrects an error resulting from elastic deformation of an elastic element in a power transmission mechanism when a moving body is moved at a high speed.

There is a need for a servo control device for controlling a feed axis which converts rotational motion of a servo motor into linear motion of a moving body by way of a ball screw, the servo control device allowing an error in positioning of a feed axis to be reduced or prevented.

SUMMARY OF THE INVENTION

According to a first aspect of the present application, a servo control device for controlling a feed axis which converts rotational motion of a servo motor into linear motion of a moving body by way of a ball screw, wherein the ball screw is supported at opposite ends thereof by a first fixed unit arranged at one end of the ball screw closer to the servo motor, and by a second fixed unit arranged at the other end of the ball screw, respectively, the servo control device comprising: a position command generating unit for generating a position command associated with a position of the feed axis; a torque command generating unit for generating a torque command for the servo motor; a thermal displacement amount calculating unit for calculating an amount of thermal displacement of the ball screw; a tension calculating unit for calculating tension acting on the second fixed unit, based on a distance from the first fixed unit to the second fixed unit, a distance from the first fixed unit to the moving body, the amount of thermal displacement calculated by the thermal displacement amount calculating unit, and the torque command generated by the torque command generating unit; a stretch/contraction amount calculating unit for calculating an amount of stretch or contraction of the ball screw during operation of the servo motor, based on the tension calculated by the tension calculating unit, the distance from the first fixed unit to the second fixed unit, the distance from the first fixed unit to the moving body, and the torque command generated by the torque command generating unit; and a position correction amount calculating unit for calculating an amount of position correction adapted to correct the position command associated with a position of the feed axis, based on the amount of stretch or contraction calculated by the stretch/contraction amount calculating unit, is provided.

According to a second aspect of the present application, the servo control device according to the first aspect further comprises a judging unit for determining whether the tension calculated by the tension calculating unit acts in a stretching direction that stretches the ball screw, or in a contracting direction that contracts the ball screw, wherein the stretch/contraction amount calculating unit further comprises: a first stretch/contraction amount calculating unit for calculating an amount of stretch of the ball screw, based on the distance from the first fixed unit to the moving body, the distance from the first fixed unit to the second fixed unit, and the torque command generated by the torque command generating unit, when the judging unit determines that the tension acts in the stretching direction; and a second stretch/contraction amount calculating unit for calculating an amount of contraction of the ball screw, based on the distance from the first fixed unit to the moving body, and the torque command generated by the torque command generating unit, when the judging unit determines that the tension acts in the contracting direction.

According to a third aspect of the present application, in the servo control device according to the second aspect, the first stretch/contraction amount calculating unit is configured to calculate the amount of stretch of the ball screw by multiplying, with a predetermined constant, a product of: the distance from the first fixed unit to the moving body; a distance from the first fixed unit to the second fixed unit; an added distance obtained by adding a value of the amount of thermal displacement calculated by the thermal displacement amount calculating unit to an entire length of the ball screw at an ordinary temperature; and the torque command generated by the torque command generating unit.

According to a fourth aspect of the present application, in the servo control device according to the second or third aspect, the second stretch/contraction amount calculating unit is configured to calculate the amount of contraction of the ball screw by multiplying, with a predetermined constant, a product of: the distance from the first fixed unit to the moving body; and the torque command generated by the torque command generating unit.

According to a fifth aspect of the present application, in the servo control device according to any of the first to fourth aspects, the distance from the first fixed unit to the second fixed unit is greater than an entire length of the ball screw at an ordinary temperature, wherein the ball screw is fixed by the first fixed unit and the second fixed unit such that the ball screw is deformable in a direction that stretches the ball screw, while the ball screw is not deformable in a direction that contracts the ball screw.

According to a sixth aspect of the present application, in the servo control device according to any of the first to fifth aspects, the thermal displacement amount calculating unit is configured to calculate the amount of thermal displacement of the ball screw, based on an average speed during a unit time.

These and other objects, features and advantages of the present invention will become more apparent in light of the detailed description of exemplary embodiments thereof as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram showing a configuration of a servo control device according to one embodiment of the present invention;

FIG. **2** is a block diagram showing a detailed configuration of a stretch/contraction amount calculating unit in FIG. **1**;

FIG. **3** is a flowchart showing a process performed by the servo control device according to the embodiment of the present invention;

FIG. **4** illustrates an exemplary configuration of a ball screw to which the present invention can be applied; and

FIG. **5** is a schematic view to explain the ball screw in various states.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention will be described with reference to the accompanying drawings. Constituent elements of the illustrated embodiment may be modified in size in relation to one another for better understanding of the present invention.

FIG. **4** illustrates an exemplary configuration of a ball screw **100** to which the present invention can be applied. The ball screw **100** includes a screw axis **102** formed with a threaded groove on an outer circumferential surface thereof, and a nut **104** formed with an internal thread on an inner circumferential surface thereof. The female screw of the nut **104** is fitted into the threaded groove of the screw axis **102** via balls (not shown). The nut **104** is fixedly provided with a table **106**, on which, for example, a workpiece (not shown) can be placed, so that the nut **104** and the table **106** can be moved together. The table **106** is one example of a moving body moved by the ball screw **100**.

The screw axis **102** of the ball screw **100** is provided with a first bracket **108** and a second bracket **110** spaced apart from each other at opposite ends **102***a* and **102***b* of the screw axis **102**, respectively. The first bracket **108** is one example of a first fixed unit, and the second bracket **110** is one example of a second fixed unit. The screw axis **102** is rotatably supported by bearings (not shown) provided inside the first bracket **108** and the second bracket **110**. Specifically, the first bracket **108** supports the screw axis **102** of the ball screw **100** such that the ball screw **100** is immovable in its longitudinal direction, while the screw axis **102** is rotatable around an axis extending in the longitudinal direction. The second bracket **110** supports the screw axis **102** of the ball screw **100** such that the ball screw **100** is non-contractable in the longitudinal direction, but is stretchable in the longitudinal direction, while the screw axis **102** is rotatable around the axis extending in the longitudinal direction. To the first bracket **108**, a servo motor **120** is connected via a coupling **112**. The servo motor **120** includes an encoder **122** for detecting information on an operational condition of the servo motor **120**, such as a rotational position and a rotational speed.

The servo motor **120** is configured to rotate in response to a command signal generated by a servo control device **10**, which will be further described below. Rotational motion of the servo motor **120** is transmitted to the screw axis **102** of the ball screw **100** via the coupling **112**. Hence, as the servo motor **120** rotates, the screw axis **102** of the ball screw **100** correspondingly rotates at a predetermined reduction ratio. Corresponding to the rotational motion of the screw axis **102**, the nut **104** reciprocates together with the table **106** in the longitudinal direction of the screw axis **102** over a region between the first bracket **108** and the second bracket **110**. In this way, the screw axis **102** of the ball screw **100** and the nut **104** function as a feed axis that converts rotational motion of the servo motor **120** into linear motion of the table **106** along the screw axis **102**.

The ball screw **100** is subject to thermal expansion due to frictional heat generated between the nut **104** and the screw axis **102** when the nut **104** is in linear motion relative to the screw axis **102**. Such thermal expansion of the ball screw **100** could result in deteriorated accuracy in positioning of the feed axis in the ball screw **100**. Thus, pretension may be sometimes applied to the ball screw **100**, in order to ensure that the ball screw **100** is held in a state where the ball screw **100** is stretched.

FIG. **5** is a schematic view to explain the ball screw **100** in various states. Part (a) of FIG. **5** illustrates the screw axis **102** of the ball screw **100** in a state where no tension is applied thereto at an ordinary temperature. In this case, the screw axis **102** has a length**0** as its natural length. Part (b) of FIG. **5** illustrates the ball screw **100** in a state where it is expanded in the longitudinal direction so as to have a length L**1** greater than the length L**0**. The ball screw **100** is fixed by the first bracket **108** and the second bracket **110** in its expanded state. The illustrated table **106** is positioned at a distance L**11** from the first bracket **108**. A distance between the table **106** and the second bracket **110** is set as a distance L**12**.

Dashed lines drawn between parts (a) and (b) in the drawing represent relationships between the corresponding portions of the ball screw **100**. For example, a portion of the ball screw **100** situated at a distance L**11** from the first bracket **108** in part (b) corresponds to a portion situated at a distance L**01** from the first bracket **108** in part (a). In other words, the distance L**11** between the first bracket **108** and the table **106** in part (b) corresponds to the distance L**01** in part (a). The distance L**12** between the table **106** and the second bracket **110** in the state of the part (b) corresponds to a distance L**02** in the state of the part (a).

In the state shown in part (b) of FIG. **5**, tension uniformly acts on the screw axis **102** of the ball screw **100**. Specifically, tension T**11** acting on the ball screw **100** on the side of the first bracket **108** from the table **106** is equal to tension T**12** acting on the ball screw **100** on the side of the second bracket **110**. Accordingly, the following Formula (1) is satisfied:

$$T11=T12=E\times\{(L1-L0)/L0\}\times A0 \quad \text{[Formula (1)]},$$

where the character E represents Young's modulus, and the character A**0** represents cross sectional area of the screw axis **102**.

The case where torque for accelerating or decelerating the table **106** is applied to the servo motor **120** in the state of the part (b) of FIG. **5**, in which the table **106** is at the distance L**11** from the first bracket **108**, will now be considered. In this case, force which moves the table **106** acts to stretch or contract the screw axis **102** of the ball screw **100**. However, since both ends **102***a* and **102***b* of the screw axis **102** are fixed in the longitudinal direction, the length L**1** of the screw axis **102** remains unchanged. As a result, part of the screw axis **102** stretches in the longitudinal direction, while the other part of the screw axis **102** contracts in the longitudinal direction, in such a way that an amount of stretch and an amount of contraction in the local parts of the screw axis **102** cancel out each other, as a whole.

Part (c) of FIG. **5** illustrates a state in which the screw axis **102** stretches or contracts when torque for accelerating the table **106** toward the first bracket **108** is applied thereto. In the state shown in part (c), the table **106** is displaced to a position at a distance L**21** from the first bracket **108**, as a result of the stretch of the screw axis **102**. Among a distance L**22** defined between the table **106** and the second bracket

110, tension T21 acting on the ball screw 100 on the side of the first bracket 108, and tension T22 acting on the ball screw 100 on the side of the second bracket 110, the following Formulae (2) to (5) are satisfied:

$$T21=E\times\{(L21-L01)/L01\}\times A0 \quad \text{[Formula (2)]};$$

$$T22=E\times\{(L22-L02)/L02\}\times A0 \quad \text{[Formula (3)]};$$

$$L21+L22=L1 \quad \text{[Formula (4)]; and}$$

$$T21-T22=F \quad \text{[Formula (5)]},$$

where the character F represents force acting so as to move the table 106 toward the first bracket 108.

By solving the above Formulae (2) to (5), the distances L21 and L22 and the tensions T21 and T22 can be obtained as in the following Formulae (6) to (9):

$$L21=L11+\{(L0\times L11\times L12)/L1\hat{}2\}\times F/(E\times A0)=L11+\{(L01\times L02)/L0\}\times F/(E\times A0) \quad \text{[Formula (6)]};$$

$$L22=L12-\{(L0\times L11\times L12)/L1\hat{}2\}\times F/(E\times A0)=L12-\{(L01\times L02)/L0\}\times F/(E\times A0) \quad \text{[Formula (7)]};$$

$$T21=E\times A0\times\{(L1-L0)/L0\}+(L12/L1)\times F \quad \text{[Formula (8)]; and}$$

$$T22=E\times A0\times\{(L1-L0)/L0\}-(L11/L1)\times F \quad \text{[Formula (9)]}.$$

In relation to the tensions T11 and T12, the following Formula (10) is satisfied:

$$T11=T12=E\times\{(L1-L0)/L0\}\times A0=E\times\{(L11-L01)/L01\}\times A0=E\times\{(L12-L02)/L02\}\times A0 \quad \text{[Formula (10)]}.$$

Accordingly, the distances L11 and L12 can be obtained by the following Formulae (11) and (12) with the distances L01 and L02, respectively:

$$L11=(L1/L0)\times L01 \quad \text{[Formula (11)]; and}$$

$$L12=(L1/L0)\times L02 \quad \text{[Formula (12)]}.$$

Therefore, a difference between the distances L11 and L21, and a difference between the distances L12 and L22, each of which corresponds to an amount of changes in positions of the feed axis before and after the torque is applied to the servo motor 120 are obtained by Formulae (13) and (14), respectively, as follows:

$$L21-L11=\{(L0\times L11\times L12)/L1\hat{}2\}F/(E\times A0)=(L0/L1)\times\{(L1-L11)/L1\}\times\{F/(E\times A0)\}\times L11 \quad \text{[Formula (13)]; and}$$

$$L22-L12=-\{(L0\times L11\times L12)/L1\hat{}2\}\times F/(E\times A0)=-(L0/L1)\times\{(L1-L11)/L1\}\times\{F/(E\times A0)\}\times L11 \quad \text{[Formula (14)]}.$$

The force F can be calculated from the following Formula (15), provided that the torque T applied to the servo motor 120 and a reduction ratio of the power transmission unit between the servo motor 120 and the ball screw 100 are determined:

$$F=(2\pi/le)\times T \quad \text{[Formula (15)]},$$

where the character le represents a lead (a length of a pitch) of the threaded groove of the ball screw 100.

In accordance with the above Formula (13), an amount of position correction corresponding to the table 106 situated at the distance L11 from the first bracket 108 can be calculated. The amount of position correction is used to correct the position of the table 106, so that the table 106 can be positioned accurately even if pretension acts on the ball screw 100.

The case where tension T22 acting on the side of the second bracket 110 is negative, i.e., the case where the tension T22 acts on the ball screw in a direction that contracts the ball screw 100 will now be considered. In this case, the end 102*b* of the screw axis 102 of the ball screw 100 protrudes from the second bracket 110. Accordingly, in this state, the end 102*b* of the screw axis 102 on the side of the second bracket 110 is a free end. Thus, tension acting on the ball screw 100 does not need to be taken into account for the purpose of calculation of an amount of stretch or contraction of the ball screw 100. An amount of position correction in this case can be determined by Formula (16), depending on the distance from the first bracket 108 to the table 106 as follows:

$$L21-L11=L11\times\{F/(E\times A0)\} \quad \text{[Formula (16)]}.$$

Based on Formula (9), the condition under which the tension T22 is negative is met when the following inequality is satisfied:

$$F>E\times A0\times(L1-L0)/L01.$$

Next, the case where thermal expansion of the ball screw 100 is taken into account will be described. If a length of the screw axis 102 of the ball screw 100 at an ordinary temperature t0 [° C.] is L0, a length Lt1 of the screw axis 102 at a temperature t1 [° C.] can be obtained by the following Formula (17):

$$Lt1=L0\times\{1+\alpha\times(t1-t0)\} \quad \text{[Formula (17)]},$$

where the character α represents a linear expansion coefficient.

In the case where the temperature of the ball screw 100 rises up to the temperature t1 [° C.], and the length L0 is stretched to the length Lt1 without tension acting thereon being taken into account, an influence of thermal expansion of the ball screw 100 can be compensated by substituting Lt1 for L0. If the length L0 is replaced with the length Lt1, since an inequality Lt1>L0 is satisfied, threshold F which determines whether the tension T22 becomes negative will be smaller. On the other hand, when the length Lt1 of the ball screw 100 at the temperature t1 [° C.] becomes greater than the distance L1 between the first bracket 108 and the second bracket 110, the tension force acting on the ball screw 100 becomes zero. Based on this observation, the distance L1 is determined so as to correspond to a length of the ball screw 100 when a temperature rises from an ordinary temperature by to the tune of 2 to 3 degrees. This allows the tension to remain acting on the ball screw 100, even when the ball screw 100 thermally expands to some extent.

The servo control device 10 for controlling the servo motor 120 will be described in detail. FIG. 1 is a block diagram showing a configuration of the servo control device 10 according to one embodiment of the present invention. The servo control device 10 includes a position command generating unit 12, a position detecting unit 14, a speed command generating unit 16, a speed detecting unit 18, a torque command generating unit 20, a moving body position detecting unit 22, a thermal displacement amount calculating unit 24, a tension calculating unit 26, a judging unit 28, a stretch/contraction amount calculating unit 30, and a position correction amount calculating unit 32. The servo control device 10 further includes a first subtractor 34 for subtracting an output value of the position detecting unit 14 from an output value of the position command generating unit 12, an adder 36 for adding an output value of the first subtractor 34 and an output value of the position correction amount calculating unit 32, and a second subtractor 38 for subtracting an output value of the speed detecting unit 18 from an output value of the speed command generating unit 16.

The position command generating unit **12** generates a position command based on a control program read out by the servo control device **10**, for example, and outputs the position command for the servo motor **120** to the first subtractor **34**. The position command for the servo motor **120** is determined in accordance with a relationship between an angular position of the servo motor **120** and a corresponding position of the feed axis of the ball screw **100**, which is a target position for the control. The relationship between the angular position of the servo motor **120** and the position of the feed axis can be obtained based on mechanical configurations of the servo motor **120** and the ball screw **100**. The position detecting unit **14** obtains an angular position of the servo motor **120** detected by an encoder **122** associated with the servo motor **120**. The detected angular position is fed back to the first subtractor **34**. The first subtractor **34** calculates an amount of position deviation which is a difference between the position command and the detected position. The result of calculation by the first subtractor **34** is output to the adder **36**. The adder **36** adds an output value of the position correction amount calculating unit **32** to the output value of the first subtractor **34** and outputs the resultant value to the speed command generating unit **16**.

The speed command generating unit **16** generates a speed command based on the amount of position deviation and an amount of position correction. The speed command for the servo motor **120** is output to the second subtractor **38**. The speed detecting unit **18** obtains a speed of the servo motor **120** detected by the encoder **122**, and feeds it back to the second subtractor **38**. The second subtractor **38** calculates an amount of speed deviation based on the speed command and the detected value of speed associated with the servo motor **120**. The second subtractor **38** outputs the calculated value to the torque command generating unit **20**. The torque command generating unit **20** generates a torque command for the servo motor **120** based on the amount of speed deviation, and outputs the torque command to the servo motor **120**. In accordance with the torque command, an electric current is supplied to the servo motor **120**, thereby driving the servo motor **120**. As a result, the table **106** is linearly moved via the ball screw **100**. In the illustrated embodiment, position feedback control and speed feedback control is performed for the servo motor **120**. However, the present invention is not limited to such a specific embodiment. For example, the servo control device **10** may be configured such that feedback control is performed in relation to a position of the feed axis in the ball screw **100** in order to indirectly control the servo motor **120**. In this case, based on an amount of deviation between a position command for the feed axis and a detected position of the feed axis, a torque command to be given to the servo motor **120** is determined. Accordingly, in relation to the present invention, a "position command associated with a position of the feed axis" may be either a position command for the feed axis, or a position command based on which a position of the feed axis can be indirectly determined (such as the position command for the servo motor **120** as described above).

The moving body position detecting unit **22** detects a position of the table **106**, and outputs the detected information on the position to the tension calculating unit **26** and to the stretch/contraction amount calculating unit **30**, respectively. The position of the table **106** can be obtained from, for example, an angular position of the servo motor **120**. Alternatively, the position of the table **106** may also be detected by a position sensor (not shown) that directly detects a position of the table **106**. The thermal displacement amount calculating unit **24** approximately calculates an amount of thermal displacement of the feed axis in the ball screw **100**, based on, for example, an operational condition of the servo motor **120**. For example, an amount of thermal displacement of the feed axis of the ball screw **100** can be calculated based on an average speed of the servo motor **120** during a predetermined sampling period. The value of the amount of thermal displacement calculated by the thermal displacement amount calculating unit **24** is output to the tension calculating unit **26**.

The tension calculating unit **26** calculates tension T>acting on the ball screw **100** on the side of the second bracket **110**, based on a distance L**1** from the first bracket **108** to the second bracket **110**, a distance L**11** from the first bracket **108** to the table **106**, an amount of thermal displacement calculated by the thermal displacement amount calculating unit **24**, and a torque command generated by the torque command generating unit **20**. The tension T**22** is calculated in accordance with Formula (9) as described above. A value of the tension T**22** calculated by the tension calculating unit **26** is output to the judging unit **28**. The judging unit **28** determines whether or not the tension T**22** is positive, i.e., whether or not the tension T**22** acts in a direction that stretches the ball screw **100** in the longitudinal direction. The result of judgment by the judging unit **28** is output to the stretch/contraction amount calculating unit **30**.

The stretch/contraction amount calculating unit **30** further includes a first stretch/contraction amount calculating unit **30***a* and a second stretch/contraction amount calculating unit **30***b*, as illustrated in FIG. **2**, in which a more detailed configuration of the stretch/contraction amount calculating unit **30** is shown. The stretch/contraction amount calculating unit **30** is configured so as to selectively activate either the first stretch/contraction amount calculating unit **30***a* or the second stretch/contraction amount calculating unit **30***b*, based on the result of judgment by the judging unit **28**. Specifically, when the judging unit **28** determines that the tension T**22** is positive, i.e., the tension T**22** acts in a direction that stretches the ball screw **100**, the first stretch/contraction amount calculating unit **30***a* calculates an amount of stretch of the ball screw **100**, based on the distance L**11** from the first bracket **108** to the table **106**, the distance L**1** from the first bracket **108** to the second bracket **110**, and the torque command generated by the torque command generating unit **20**. The first stretch/contraction amount calculating unit **30***a* calculates the amount of stretch of the ball screw **100** in accordance with the above-described Formula (13).

On the other hand, when the judging unit **28** determines that the tension T**22** is negative, i.e., the tension T**22** acts in a direction that contracts the ball screw **100**, the second stretch/contraction amount calculating unit **30***b* calculates an amount of contraction of the ball screw **100**, based on the distance L**11** from the first bracket **108** to the table **106**, and the torque command generated by the torque command generating unit **20**. The second stretch/contraction amount calculating unit **30***b* calculates the amount of contraction of the ball screw **100** in accordance with the above-described Formula (16).

The amount of stretch or contraction calculated by the stretch/contraction amount calculating unit **30** is output to the position correction amount calculating unit **32**. The position correction amount calculating unit **32** calculates an amount of position correction, based on the amount of stretch or contraction of the ball screw **100** which has been obtained by taking into account an influence of pretension applied to the ball screw **100**. The amount of position

correction is intended to correct a position command for the servo motor **120** associated with a position command for the feed axis. The calculated amount of position correction is output to the adder **36** by the position correction amount calculating unit **32**.

Referring to FIG. **3**, a process performed by the servo control device according to the present embodiment will be described. FIG. **3** is a flowchart showing the process performed by the servo control device.

Upon a command signal, e.g., a signal for positioning the table **106** at a predetermined position, being received by the servo control device **10**, the position command generating unit **12** is activated to generate a position command for the servo motor **120** (step S**101**). Based on the position command output from the position command generating unit **12**, and a detected position value output from the position detecting unit **14**, a speed command for the servo motor **120** is generated by the speed command generating unit **16** (step S**102**). Then, based on the speed command output from the speed command generating unit **16**, and a detected speed value output from the speed detecting unit **18**, a torque command for the servo motor **120** is generated by the torque command generating unit **20** (step S**103**). The above process at steps S**101** through S**103** may be a general process carried out in order to control the servo motor **120**.

Subsequently, a distance L**11** between the first bracket **108** situated closer to the servo motor **120** and the table **106** is obtained, based on the detected information by the moving body position detecting unit **22** (step S**104**). A position of the table **106** can be obtained by using a detected value of the encoder **122** associated with the servo motor **120**, or by using a position sensor that detects a position of the table **106**, as described above. Further, an amount of thermal displacement of the ball screw **100** is calculated by the thermal displacement amount calculating unit **24** (step S**105**). The amount of thermal displacement calculated at step S**105** is approximately calculated, e.g., by taking into account an operational condition of the servo motor **120**.

Then, tension T**22** applied to the ball screw **100** on the side of the second bracket **110** situated farther from the servo motor **120** is calculated by the tension calculating unit **26** (step S**106**). The tension calculating unit **26** calculates the tension T**22** in accordance with Formula (9), based on: (a) the distance L**11** from the first bracket **108** to the table **106**; (b) the distance L**1** from the first bracket **108** to the second bracket **110**; (c) the amount of thermal displacement calculated by the thermal displacement amount calculating unit **24**; and (d) force F calculated from the torque command in accordance with Formula (15). In this process, the length L**0** in the state where no tension is applied to the ball screw **100** is replaced with a value that is adjusted based on the amount of thermal displacement calculated by the thermal displacement amount calculating unit **24**.

Subsequently, based on the tension T**22** calculated by the tension calculating unit **26**, a direction in which the tension T**22** acts on the ball screw **100** is determined. In other words, the judging unit **28** determines whether or not the tension T**22** acts in a direction that stretches the ball screw **100** (step S**107**).

When it is determined at step S**107** that the tension T**22** acts in a stretching direction that stretches the ball screw **100**, the process proceeds to step S**108**, and an amount of stretch of the ball screw **100** is calculated by the stretch/contraction amount calculating unit **30**. Specifically, the first stretch/contraction amount calculating unit **30***a* of the stretch/contraction amount calculating unit **30** calculates an amount of stretch of the ball screw **100** in accordance with Formula (13), based on: (e) the distance L**11** from the first bracket **108** to the table **106**; (f) the distance L**1** from the first bracket **108** to the second bracket **110**; and (g) the force F calculated in accordance with Formula (15) using the torque command generated by the torque command generating unit **20** (step S**108**).

When it is determined at step S**107** that the tension T**22** acts in a direction opposite to the stretching direction, the process proceeds to step S**109**, and an amount of contraction of the ball screw **100** is calculated by the stretch/contraction amount calculating unit **30**. Specifically, the second stretch/contraction amount calculating unit **30***b* of the stretch/contraction amount calculating unit **30** calculates an amount of contraction amount of the ball screw **100** in accordance with Formula (16), based on: (h) the distance L**11** from the first bracket **108** to the table **106**, and (i) the force F calculated in accordance with Formula (15) by using the torque command generated by the torque command generating unit **20** (step S**109**).

An amount of position correction for the feed axis of the ball screw **100** is then calculated by the position correction amount calculating unit **32**, based on the amount of stretch or contraction of the ball screw **100** calculated at step S**108** or step S**109** (step S**110**). The amount of position correction calculated at step S**110** is output to the adder **36** where it is incorporated into an amount of position deviation which represents an error between the position command for the servo motor **120** and the detected position.

In this way, according to the servo control device **10** of the present embodiment, an amount of stretch or contraction of the ball screw **100** is calculated by taking into account the tension acting on the ball screw **100**. This allows the feed axis of the ball screw **100** to be positioned more accurately. When the ball screw **100** is in acceleration or deceleration, the amount of stretch or contraction of the ball screw **100** varies, depending on the tension acting on the ball screw **100**. According to the present embodiment, even in such a case, a position of the ball screw **100** will be corrected. Further, it is also possible to correct a position of the feed axis of the ball screw **100** even when the amount of stretch or contraction amount of the ball screw **100** is locally different, depending on distances between the servo motor **120** and the moving body (table **106**). Furthermore, according to the present embodiment, a position of the feed axis of the ball screw **100** can be corrected any time when the ball screw **100** is in acceleration or in deceleration.

EFFECT OF THE INVENTION

With the servo control device according to the present invention, an amount of stretch or contraction of the ball screw is calculated by taking into account an influence of tension acting on the ball screw. Accordingly, an error in positioning of the feed axis due to the tension acting on the ball screw can be prevented from occurring.

The various embodiments of the present invention are described above. However, it is apparent for a person skilled in the art that the present invention can be embodied by arbitrarily combining features of the embodiments disclosed explicitly or implicitly in the present specification. Although the invention has been shown and described with exemplary embodiments thereof, it should be understood by a person skilled in the art that the foregoing and various other changes, omissions and additions may be made therein and thereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A servo control device for controlling a feed axis which converts rotational motion of a servo motor into linear motion of a moving body by way of a ball screw,

wherein the ball screw is supported at opposite ends thereof by a first fixed unit arranged at one end of the ball screw closer to the servo motor, and by a second fixed unit arranged at the other end of the ball screw, respectively,

the servo control device comprising:

a position command generating unit for generating a position command associated with a position of the feed axis;

a torque command generating unit for generating a torque command for the servo motor;

a thermal displacement amount calculating unit for calculating an amount of thermal displacement of the ball screw;

a tension calculating unit for calculating tension acting between the ball screw and the second fixed unit, based on a distance from the first fixed unit to the second fixed unit, a distance from the first fixed unit to the moving body, the amount of thermal displacement calculated by the thermal displacement amount calculating unit, and the torque command generated by the torque command generating unit;

a stretch/contraction amount calculating unit for calculating an amount of locally-generated stretch or contraction of the ball screw during operation of the servo motor, based on the tension calculated by the tension calculating unit, the distance from the first fixed unit to the second fixed unit, the distance from the first fixed unit to the moving body, and the torque command generated by the torque command generating unit; and

a position correction amount calculating unit for calculating an amount of position correction adapted to correct the position command associated with a position of the feed axis, based on the amount of locally-generated stretch or contraction calculated by the stretch/contraction amount calculating unit.

2. The servo control device according to claim 1, further comprising a judging unit for determining whether the tension calculated by the tension calculating unit acts in a stretching direction that stretches the ball screw, or in a contracting direction that contracts the ball screw,

wherein the stretch/contraction amount calculating unit further comprises:

a first stretch/contraction amount calculating unit for calculating an amount of locally-generated stretch of the ball screw, based on the distance from the first fixed unit to the moving body, the distance from the first fixed unit to the second fixed unit, and the torque command generated by the torque command generating unit, when the judging unit determines that the tension acts in the stretching direction; and

a second stretch/contraction amount calculating unit for calculating an amount of locally-generated contraction of the ball screw, based on the distance from the first fixed unit to the moving body, and the torque command generated by the torque command generating unit, when the judging unit determines that the tension acts in the contracting direction.

3. The servo control device according to claim 2, wherein the first stretch/contraction amount calculating unit is configured to calculate the amount of locally-generated stretch of the ball screw by multiplying, with a predetermined constant, a product of:

the distance from the first fixed unit to the moving body;

a distance from the first fixed unit to the second fixed unit;

an added distance obtained by adding a value of the amount of thermal displacement calculated by the thermal displacement amount calculating unit to an entire length of the ball screw at an ordinary temperature; and

the torque command generated by the torque command generating unit.

4. The servo control device according to claim 2, wherein the second stretch/contraction amount calculating unit is configured to calculate the amount of locally-generated contraction of the ball screw by multiplying, with a predetermined constant, a product of:

the distance from the first fixed unit to the moving body; and

the torque command generated by the torque command generating unit.

5. The servo control device according to claim 1, wherein the distance from the first fixed unit to the second fixed unit is greater than an entire length of the ball screw at an ordinary temperature, and

wherein the ball screw is fixed by the first fixed unit and the second fixed unit such that the ball screw is deformable in a direction that stretches the ball screw, while the ball screw is not deformable in a direction that contracts the ball screw.

6. The servo control device according to claim 1, wherein the thermal displacement amount calculating unit is configured to calculate the amount of thermal displacement of the ball screw, based on an average speed during a unit time.

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